

Bottom Boundary Layer and Suspended Sediment Dynamics: Model-Data Comparisons

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LONG-TERM GOALS

The long term objective of my research is to understand and predict the dynamics of wave and current bottom boundary layers and suspended sediment over natural seabeds in the shallow water environment.

OBJECTIVES

The objectives of this research project are to expand the capabilities of an existing numerical model of bottom boundary layer (BBL), sediment transport, and morphologic evolution physics for application on natural beaches and to evaluate the resulting model with field observations of near bed velocity and concentration. I use the model-data comparisons to help interpret field observations over complex topography and to quantify the strengths and weaknesses in the model's physics.

APPROACH

We have modified an existing 2-dimensional bottom boundary layer model, Dune2D, for application with natural waves and seabed morphology. Prior to this project, the Dune2D model, developed by researchers at the Technical University of Denmark, assumed a single frequency horizontally oscillating free stream forcing with a variable current, a rigid lid upper boundary condition and a periodic lower boundary condition. The model employs either a zero-, first-, or second-order turbulence closure scheme to resolve the relevant dynamics of wave and current boundary layers over smooth and rough movable sand beds as well as several schemes to model sediment transport. We have maintained the established physics, but modified the forcing and boundary conditions.

Second-order closure models, such as Dune2D, have favorably been compared with laboratory observations (Fredsoe et al., 1999 and Andersen, 1999), but have not been compared with field observations. The model is being compared with velocity observations obtained during Duck94 (Foster et al, 2000) and SandyDuck by collaborators Thornton and Stanton of the Naval Postgraduate School. The model skill will be quantified with time-averaged and time-varying statistics. We will calculate the root-mean-square deviations (RMSD) of the: turbulent kinetic energy, dissipation, and velocity amplitude and phase for each data set. The time-varying statistics will be evaluated with the RMSD between the model generated and observed quantities at each phase of the wave. This

technique will allow us to identify particular wave amplitudes and phases when the comparisons are favorable and unfavorable.

WORK COMPLETED

Thus far, several technical objectives have been met. First, I have modified the model to allow for forcing of measured velocity profiles over measured topography. This was accomplished at the Ohio State University and during a visit to the Danish Technical University. Second, I have evaluated the model with multiple data sets measured during the SandyDuck experiment by Stanton and Thornton of the Naval Postgraduate School which cover the morphologic range from flat beds to megaripples. One peer reviewed paper has been submitted and another two are near completion.

RESULTS

The model-data comparisons have thus far identified several interesting phenomena. In the example below, the model is compared with acoustic doppler profiler observations made in several meters of water over a rough bed with a definitive 25 cm high bedform (Figure 1). The model-data comparisons of mean and root-mean-square velocity at the instrument location are generally excellent (Figure 2). As expected the model predicted a boundary layer thickness for flow over the measured bedform to be significantly higher than for flow over a flat rough bed.

Figure 1 shows a time series of observed suspended sediment concentration over the lower 50 cm of the water column. As is often found, the suspension is highly intermittent. Figure 4 shows three two-dimensional snapshots of the model predicted velocity and suspended sediment at 360, 362, and 366 seconds. As can be seen in the snapshot at 360 seconds, the model predicts incipient motion to occur at the crest of the bedform (see upper panel of Figure 4). As flow decelerates an eddy shed from the bedform crest entrains suspension and advects it past the sensor (see middle panel of Figure 4). When the flow has reversed direction the plume begins to settle out as it is advected in the offshore direction.

Statistically, both the model predictions and observations show that at the BCVD location plumes are present during the decelerating phase of the wave crests. Figure 5 shows the average concentration of the plumes at 12 cm above the bed as a function of wave phase. Clearly had the instrument been located elsewhere the plumes would be observed at different wave phases.

These results are an example of how we may now directly compare field observations of velocity and concentration at a known location over complicated topography with sophisticated bottom boundary layer models. Results like these will be used to evaluate the model skill, improve the model physics and improve our interpretation of observations in the natural environment.

Figure 1. The observed seabed morphology shows a well defined two dimensional megaripple. The red line denotes the location of the BCDV profiler.

Figure 2. Comparisons between measured (\square) and modelled (—) mean and root-mean-square vertical (left panels) and horizontal (right panels) velocities.

IMPACT/APPLICATIONS

This work is relevant to society and ONR's objectives in two distinct ways. First, existing predictive models of wave shoaling are dependent on acceptable parameterization of the of the BBL dissipation. Current models for estimating the BBL dissipation rely heavily on existing laboratory observations in idealized conditions and not in natural environments. Using both field observations and numerical modelling, this investigation will further our understanding and predictive capability of BBL dissipation in natural environments. Secondly, these results should improve our ability to predict transport and burial of movable objects on the sea floor in the coastal environment by increasing our understanding of the physics at the fluid-sediment interface.

RELATED PROJECTS

This project relies on the close collaboration with the Naval Postgraduate School (PI's Stanton and Thornton) and with current and future scientific exchanges with the Danish Technical University (PI's Fredsoe and Andersen). The initial scientific exchange was funded by a NICOP exchange (Co-PI's Diegaard and Bowen).

Figure 3. A time series of observed free stream velocity (upper panel) and observed suspended sediment profiles (lower panel). Positive flow is directed offshore.

Figure 4. Two-dimensional snap shots of \log_{10} suspended sediment concentration (color intensity) and velocity (vector) at 360 (upper panel), 362 (middle panel), and 366 (lower panel) seconds.

Figure 5 .The observed (upper panel) and modelled (lower panel) phase space average of suspended sediment concentration at 12 cm above the bed. Negative velocity represents onshore directed flow.

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